
Fluorescing inertinite macerals in Indian Gondwana coals with remarks on their genesis, terminology and coking potentiality

Basant K. Misra & Bhagwan D. Singh

Misra BK & Singh BD 1996. Fluorescing inertinite macerals in Indian Gondwana coals with remarks on their coking potentiality. *Palaeobotanist* 43(3): 78-84.

The communication documents the presence of fluorescing structured inertinite macerals in the Indian Permian Lower Gondwana coals of Raniganj, Rajmahal and Singrauli coalfields. However, quantitative assessment of the maceral has been carried out on the coals of Turra seam from Singrauli Coalfield. It was observed that some of the semifusinite and fusinite fluoresced with dull reddish-brown to dark brown colour with almost identical intensity and colour as that of the associated perhydrous vitrinite. It seems that the gymnospermous plants, chiefly responsible for the formation of Gondwana coals, were highly resinous and the tissues were also selectively impregnated with resins. The resin has an inherent tendency to get readily oxidized on aerial exposure and when such resin impregnated tissues were only partially oxidized they produced the fluorescing inertinite macerals with well-preserved cellular structure. A critical analysis of published literatures on the reactivities of vitrinite and inertinite macerals in the Indian Gondwana coals during carbonization revealed that there are certain misconceptions not only about their identification but also coking behaviour. These aspects have also been discussed. The study of coals under fluorescence mode seems to hold promise for the proper assessment of reactive inertinite macerals in Indian Permian coals.

Key-words— Petrology, Inertinite maceral, Fluorescing inertinite, Genesis, Gondwana.

Basant K. Misra & Bhagwan D. Singh, Department of Biodiagenesis, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

सारांश

भारतीय गोंडवाना कोयलों में प्रतिदीप्तिय इनर्टिनाइट मेसीरल तथा इनकी उत्पत्ति, नामपद्धति एवं कोयलीभवन पर टिप्पणियाँ

बसन्त कुमार मिश्र एवं भगवानदास सिंह

प्रस्तुत शोध-पत्र में रानीगंज, राजमहल एवं सिंगरौली कोयला-क्षेत्रों के भारतीय परमी अधरि गोंडवाना कोयलों में प्रतिदीप्तिय इनर्टिनाइट मेसीरलों की उपस्थिति का अध्ययन किया गया है तथापि सिंगरौली कोयला-क्षेत्र से तुरा सीम के कोयलों में विद्यमान मेसीरल का परिमाणात्मक मूल्यांकन किया गया है। यह प्रेक्षित किया गया है कि कुछ अर्धफ्यूजीनाइट एवं फ्यूजीनाइट प्रायः सहयुक्त परहाइड्रस विटीनाइट के समान तीव्रता एवं लाल भूरे रंग से गहरे भूरे रंग में प्रतिदीप्ति करते हैं। ऐसा अनुमान है कि अनावृतबीजी पौधों जिनसे मुख्यतया गोंडवाना कोयलों का निर्माण हुआ है, में रेजिन की अत्यधिक मात्रा विद्यमान थी तथा इनके ऊतकों में भी रेजिन विद्यमान था। वास्तव में रेजिन में यह गुण है कि यह हवा के सम्पर्क में आने पर शीघ्र ही ऑक्सीकृत हो जाता है और जब इस प्रकार के रेजिन युक्त ऊतकों का ऑक्सीकृत होना होता है तो सुपरिरीक्षित कोशिकीय संरचनाओं से युक्त ये प्रतिदीप्तिय इनर्टिनाइट मेसीरलों का निर्माण करते हैं। इसी विषय पर प्रकाशित साहित्य के अध्ययन से पता चलता है कि इन कोयलों के अभिनिर्धारण में ही नहीं अपितु इनके कोयलीभवन के बारे में भी भ्रान्तियाँ हैं। इस शोध-पत्र में इन पहलुओं पर भी विवेचना की गई है।

THE term "inertinite" was introduced into coal petrography by Stach (1952) in order to group together all

* The terms 'semivitrinite' and 'semifusinite A' being the names for a single maceral have been used ambiguously in literature (refer Chaudhuri & Ghose, 1978; Ghose *et al.*, 1987; Chakrabarti, 1987). The Bureau of Indian Standards (1992, p.2) has retained the term 'semivitrinite' In the present paper only ICCP terminology has been followed.

coal macerals which were thought to be infusible during carbonization. This assumption was based on the observation of almost unaltered inclusions of semifusinite, fusinite and macrinite in otherwise fused coke. Subsequently large scale coking experiments demonstrated that during carbonization a substantial proportion of inertinite, in fact, is not inert but

soften and becomes integrated with the coke matrix (for details refer Diessel & Wolff-Fischer, 1987). However, there is much disagreement in the literature about the actual levels of reactivity. Generally, it is believed that semifusinite of a slightly higher reflectance than the associated vitrinite of a coal is reactive.

On the basis of coking behaviour during carbonization test carried out on semifusinite of the Indian Gondwana coals, Chaudhuri and Ghose (1978) concluded that the maceral could conveniently be divided into two distinct types: (i) typical infusible semifusinite, and (ii) fusible or transitional semifusinite-intermediate between vitrinite and typical infusible semifusinite called semivitrinite* or semifusinite A* (Ro max. 0.2-0.3% higher than that of associated vitrinite - BIS, 1992). According to them, about 8 to 20 per cent of semifusinite A or semivitrinite may be present in coking coals. In view of the presence of substantial amounts of transitional semifusinite, Ghose and Chaudhuri (1979) have suggested that the actual amount of fusible and infusible semifusinites should be taken into account for the prediction of coke quality from petrographic constituents, rather than to assume 1/3 of the semifusinite is fusible or reactive and 2/3 of the semifusinite infusible or inert (Ammosov *et al.*, 1957; Schapiro *et al.*, 1961). However, according to Stach *et al.* (1982, p. 429) "semifusinite with reflectance exceeding that of vitrinite by about 0.15-0.20% remains entirely inert during carbonization"

Analysis of inertinite contained in a coal under fluorescence mode has been found to be quite useful in distinguishing and assessing fusible, partly fusible and infusible inertinites with a fair degree of reliability and compatibility with the results of carbonization tests. The adaptation of fluorescence microscopy by Diessel (1985) and Diessel and Wolff-Fischer (1987) to the study of inertinite macerals of certain Permian (Australian) and Carboniferous (German) coals was carried out by increasing the wavelength of the exciter beam (from blue to green light) and certain modifications in instrumentation.

The present study is a preliminary one aimed mainly for the estimation of fluorescing and non-fluorescing inertinite fractions in Indian Gondwana coals. However, caking/coking properties of semivitrinite/semifusinite A and clues relating with the

genesis of fluorescing structured inertinites have also been discussed. For the purpose of study, 10 inertinite-rich (42.4-64.8%) coal samples were utilized from the Turra seam of Singrauli Coalfield. It is the lowermost workable coal seam of the field and is associated with the Early Permian Barakar Formation of Lower Gondwana sequence. For geological and petrographic details of the coal seam please refer Misra and Singh (1990).

METHODS OF ANALYSIS

Fluorescence microscopic investigation has been carried out under blue light (filter block H3; 420-490 nm violet-blue excitation) using 150 Watt ultra high pressure Xenon lamp as excitation source on a Leitz MPV-3 unit. Fluorescence-free immersion oil and an NPL Fluotor objective (oil) of 25 magnification with a 0.75 numerical aperture has been used.

For the quantitative assessment under fluorescence mode, 200 points on macerals of the inertinite group have been counted and the results are expressed as volume per cent (vol.%) for fluorescing and non-fluorescing inertinite macerals on mineral matter-free basis (m.m.f.%). However, maceral analysis on polished particulate coal pellets, carried out in normal mode, was based on 500 points count.

INERTINITE IN TURRA SEAM, SINGRAULI COALFIELD

The inertinite macerals are well represented (20-66%) in the coals of the Turra seam formed chiefly of semifusinite and fusinite macerals (Misra & Singh, 1990). These macerals are also responsible for the subhydrous nature of the coals in general. Most of these inertinites have obscured cellular structure. Fusinitized bark tissues (of degrado-, pyro- and rank varieties) and transitional stages (from vitrinite to semifusinite and semifusinite to fusinite) are readily observed. Cell walls of the fusinitized tissues are relatively thinner than in the semifusinite. Fusinitized tissues with thick cell walls and fusinitized corpocollinite bodies have also been observed. Inertodetrinite and resino-inertinites (= fusinitized resins) are very common in these coals, whereas macrinite and micrinite are common. In certain instances, these macerals are intimately mixed with mineral matter with the result the coals yield high amount of ash.

OPTICAL PROPERTIES OF INERTINITE (RESULTS)

The maceral group in coal is traditionally characterized by its morphology and reflectance. The first property serves to make a distinction between structured (e.g., semifusinite/fusinite) and unstructured (e.g., macrinite) inertinites. The inertinite has higher reflectance than the other two maceral groups—vitrinite and liptinite (or exinite) of the host coal. The colour of the semifusinite/fusinite is widely variable depending upon the types present. Whitish-grey to white colour characterize the semifusinite of Singrauli coals. Degradofusinite generally shows white to bright white colours, whereas the pyro and rank fusinites have bright white to yellowish-white or sometimes even whitish-yellow colour. The coals of the Turra seam have reached a rank equivalent to sub-bituminous A to high volatile bituminous C stages (Ro max. 0.40-0.60%).

On a detailed observation under blue light excitation, made on 192 coal samples of the Barakar and Raniganj formations (Lower Gondwana) from the Singrauli (114 samples), Rajmahal (42 samples) and Raniganj (36 samples) coalfields of India, it was found that 'rank' semifusinite and fusinite (with slightly higher reflectance than the associated semifusinite) with well-preserved and thick-walled cellular structure exhibited dull reddish-brown to dark brown fluorescence colours with weak to very weak intensities (Pl. 1, figs 1-4). Those fluorescing with dull reddish-brown colour exhibited fluorescence a few second later than the associated perhydrous vitrinite. Whereas, the inertinite with dark brown colour took a little longer time to fluoresce than that of the former type. Their alteration effect could not be observed convincingly even after 5 to 7 minutes of constant irradiation.

In addition to semifusinite/fusinite, it was also found that a fraction of inertodetrinite with semifusinitic reflectivity fluoresces with similar colours (dull reddish-brown to dark brown) as that of the structured inertinites. On the other hand, degradosemifusinite/fusinite and structured fusinite with high to very high reflectivity, macrinite and resino-inertinite were non-fluorescing.

The fluorescence colour and intensity of the inertinite macerals are lower than the associated perhydrous vitrinite, formed chiefly by desmocollinite

and telocollinite fractions, but occasionally both intensity and colour are almost identical. The studied coal samples of the Turra seam have predominance of inertinite macerals (42.4-64.8%). The recorded proportion of fluorescing inertinite (5.2-10.0% of the total inertinite content, Table 1) in these coals is, therefore, additional reactive/partly reactive constituent of the total reactive macerals in Indian Lower Gondwana coals.

Because of the weak fluorescence intensity, under blue light excitation, it was difficult to obtain good and convincing photomicrographs of fluorescing inertinite. It may be possible that certain modifications in instrumentation and by increasing wavelength of the exciter beam (green light) better results may be obtained as suggested by Diessel (1985) and Diessel and Wolff-Fischer (1987).

Table 1-Proportions of inertinite macerals (semifusinite and fusinite) in the Turra coal seam of Singrauli Coalfield

Colliery/ Sample nos.	As analysed under normal mode (vol.%)			Under fluorescence mode (vol.% on m.m.f. basis)	
	Semi- fusinite	Fusinite	Total inertinite	Fluorescing*	Non- fluorescing
Kakri-2	28.6	32.0	64.8	10.0	90.0
Kakri-3	24.6	24.8	53.8	8.0	92.0
Kakri-5	22.2	28.6	56.2	6.8	93.2
Kakri-6	18.4	20.4	46.6	5.6	94.4
Kakri-9	15.2	23.6	52.4	5.2	94.8
Kakri-10	13.6	19.6	45.6	6.4	93.6
Jayant-1	15.6	24.6	42.6	7.6	92.4
NCSM-3/47 (Moher)	14.0	31.0	58.0	8.0	92.0
Gorbi-1 (I bench)	16.0	23.2	43.6	7.5	92.5
Gorbi-1 (II bench)	12.6	18.8	42.4	6.2	93.8

* Since, observation on inertodetrinite was made after finalization of the paper, its quantitative estimation has not been made.

GENESIS OF FLUORESCING INERTINITE MACERALS

On the basis of palaeobotanical evidences, it is now well established that Indian Permian coal seams were predominantly formed from a complex group of gymnospermous plants—Glossopteridophyta under humid temperate climate with marked

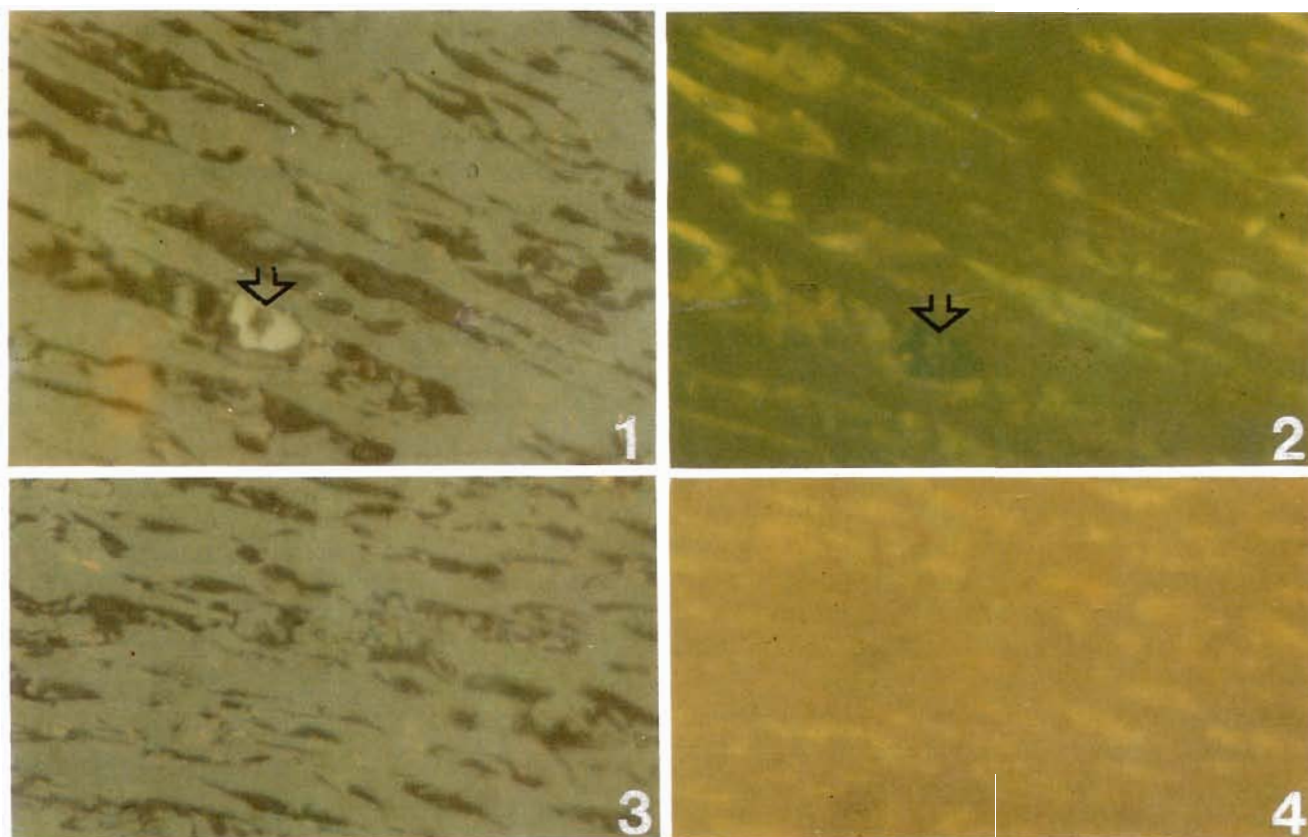


PLATE 1

(All photomicrographs were taken on polished surface using oil immersion)

- | | | | |
|----|--|----|---|
| 1. | Semifusinite (structured) under normal incident light. | 3. | Semifusinite (structured) under normal incident light. |
| 2. | Same as 1 under blue light excitation showing dark brown colour. Mark the highly reflecting inertodetrinite piece (non-fluorescing). | 4. | Same as 3 under blue light excitation showing reddish-brown colour. |

seasonal fluctuations (Misra & Singh, 1990). These plants—*Glossopteris* proliferated most and grew in wide ranging habitats as low land subaquatic and upland vegetation and as thick forests along river valleys during Permian.

A synthesis of the available palaeobotanical and biopetrographic information on Indian Lower Gondwana coals led Misra *et al.* (1990, pp. 281-282) to conclude that arborescent gymnospermous vegetation existed since Early Permian and that resin producing trees were quite common which became abundant during Late Permian. They also proposed that a fractions of resinite present in these coals were

variably oxidized and also in many cases devolatilized to produce wide range of shape, size and morphology on them before they transformed into resinoinertinites. However, the whereabouts of the remaining resinite fraction which was present originally but did not form resinoinertinite nor accounted for by the amount of resinite maceral present in these coals remained a mystery (Misra, 1992, p. 288).

In certain resin-rich plants "the resin is squeezed into cell walls" of the wood tissues "and this saturation of cell walls with resin (resinization) is a characteristic feature of conifer" (Stach *et al.*, 1982, p. 253). In Indian Lower Gondwana sequence mega-plant fossil

records with coniferalean affinity are represented commonly by *Buriadia* and *Walkomiella* in Early Permian Karharbari and Barakar formations. In the succeeding Late Permian Raniganj Formation only *Searsolia* is found (Pers. commun. Drs H.K. Maheshwari & A.K. Srivastava, 1994). On the basis of genetic morphological features, Bharadwaj (1974, p. 32) reported that commonly to frequently occurring Early Permian pollen genus *Potonieisporites* has coniferalean affinity. In addition to this, certain other resin producing plants were also inhabiting during Permian period (Misra *et al.*, 1990).

The "rank fusinite" attains high reflectance only during early coalification (Stach *et al.*, 1982). Possibly, they originate from cell walls which were initially impregnated with certain bituminous or resinous substances or that still contained cellulose in the lignite stage. Both cellulose and resins generate bitumen relatively early during coalification (Teichmüller, 1989, p. 25). The resin in plants readily reacts with oxygen when exposed to atmosphere and the oxidation involves changes in their original chemical composition (Stach *et al.*, 1982).

On the basis of preceding evidences, it is quite reasonable to presume that a certain fraction of resinite and/or bituminous substances originally present in the plants, either in the form of tissue impregnation or got impregnated in tissues later during early stages of coalification. These resin/bitumen impregnated tissues were later variably oxidized. Those oxidized partially produced fluorescing fraction of semifusinite and fusinite with well-preserved cellular structures, whereas highly oxidized tissues produced highly reflecting and non-fluorescing fusinites. It is also possible that certain amount of preserved cellulose, up to lignite stage, in tissues might have also contributed to the formation of some fluorescing inertinite.

COKING PROPERTIES OF VITRINITE AND FLUORESCING (REACTIVE) INERTINITE

Chakrabarti (1987, pp. 249, 256) reports that most of the "fusinite and semifusinite show well-preserved cell lumens which at places are filled with 'secondary' resin or exsudatinitite" in coals of five seams of northern sector in Sohagpur Coalfield. Such inertinites, according to him, "have been classed as reac-

tive/fusible inertinite in Australian coals by Diessel (1985)". Chakrabarti (1992, pp. 23) further states that "resin-filled fusinite and semifusinite in Australian coals show varying degree of reactivity and contributes 45 per cent of total inert contents in the coals". In India, exsudatinitite filled inertinites (yellow fluorescing) have been recorded between 12 to 25 per cent (of the total inertinite) in coking coals from Raniganj, Jharia, Bokaro and Sohagpur coalfields (Chakrabarti, 1992).

Inertinites with yellow fluorescing cell fillings ('fluorescing liquid expulsions' or 'oil expulsions') are known already from American, Canadian and German coals having R_m between 0.45 to 1.05 per cent (Stach *et al.*, 1982; Teichmüller & Durand, 1983). However, this cell filling or 'oil expulsion' is not a maceral (Stach *et al.*, 1982, table 29c; Teichmüller, 1986, p. 583). It may be generated partly in the bituminization range of coalification, by the interaction between bitumen substances in coals (e.g., perhydrous vitrinite) and monostyrol-rich embedding resin (palatal/epoxy) of the pellet (Teichmüller & Durand, 1983, p. 208). Reaction between embedding resin and coal particles has been also emphasized by Misra and Singh (1994) in Indian coals. Taylor *et al.* (1989, p. 2) referring studies on inertinites of Australian Permian (specially Bulli Seam) coals and carbonization experiments states that "there is evidence that the fusibility of both vitrinite and inertinite is correlated with its fluorescence intensity....".

Evidently, the conclusions of Chakrabarti (1987, 1992) that inertinites with bright yellow fluorescing cell fillings are fluorescing inertinites like that reported by Diessel (1985) and Diessel and Wolff-Fischer (1987) is not correct. Since, "for all practical purposes resinite does not form coke" (Stach *et al.*, 1982, p. 435) and any other liptinitic maceral with a tendency to soften during heating would simply cause breaking of the inertinite into pieces. Therefore, in no case there can be any impact on the inert behaviour of such inertinites.

It is well established that the "newly generated bitumen", during in the rank range of R_o max. 0.5 to 1.10 per cent renders the vitrinite "to soften and agglomerate" (Teichmüller, 1987, p. 141), that is coals develop caking property. This relationship has been confirmed by comparing fluorescence of vitrinite and

coking parameters (Ottenjann *et al.*, 1981, 1982; Teichmüller, 1982; Lin *et al.*, 1986).

Thus, the fluorescence property and variable fusibility of a certain fraction of semifusinite during coking tests are very much related with each other (Diessel, 1985; Diessel & Wolff-Fischer, 1987; Teichmüller, 1987; Taylor *et al.*, 1989). In fact, identification of semivitrinite or pseudovitrinite, because of its low coking power than normal perhydrous vitrinite, does not supplement to the conventionally accepted reactive fraction of total vitrinite + liptinite. On the other hand, identification and quantification of fluorescing inertinite in Gondwana coals rectify the quantum of 1/3 semifusinite reactive concept of earlier workers when assessing coking potentiality of inertinite-rich Gondwana coals on the basis of biopetrography. Therefore, higher than 1/3 of semifusinite content in a coking coal on one hand adds to the overall tally of reactive macerals and on the other explains certain variations in coking property of coals in case the content of reactive semifusinite is either higher or lower than the 1/3 limit.

TERMINOLOGY

Chaudhuri and Ghose (1978, p. 137) referring particularly about coking coals of Jharia Coalfield state that "though they produce a good coke, generally have a substantially higher inert content" and also that "some of these coking coals contain substantial proportion of fusible semifusinite... .. and this semifusinite should be considered as a distinct maceral of Indian coking coals". They are of the view that such transitory material between vitrinite and semifusinite "may be best called as semi- vitrinite". In later publications, Ghose *et al.* (1987) and Chakrabarti (1987, 1992) resorted to call the fusible semifusinite as semi-vitrinite and semifusinite-A or semi-vitrinite respectively. Both 'semivitrinite' (Ammosov *et al.*, 1964) and 'pseudovitrinite' (Benedict *et al.*, 1968) are the terms for a strongly reflecting vitrinite associated with vitrinite A (telocollinite) and B (desmocollinite) in a coal. Evidently, they are synonymous (Stach *et al.*, 1982, p. 235, fig. 72d). However, optical properties of only pseudovitrinite have been properly defined for identification (reflectance at least 0.025% higher than the associated vitrinites). The "coking power" of pseudovitrinite is "inferior to that of normal

vitrinite, and in extreme cases they may behave in an entirely inert manner" (Stach *et al.*, 1982, p. 431).

The semivitrinite as defined in Bureau of Indian Standards (1992, pp. 2) : "is a transitory component between vitrinites and semifusinites... .. It shows very fine cell structures or may even sometimes structureless and has a reflectance value of about 0.2 to 0.3 per cent higher than that of the associated vitrinites". The higher reflectance value (0.2-0.3%) of the semivitrinite than the associated vitrinites, evidently makes it maceral semifusinite rather than to be clubbed with maceral vitrinite as proposed. In fact, semifusinitic nature of the maceral semivitrinite (?) is evident in figures 1 and 3 of Chaudhuri and Ghose (1978).

In view of the preceding facts, we are inclined to believe that the semifusinite-A or semivitrinite is nothing but pseudovitrinite but semivitrinite/pseudovitrinite as recognized by Chaudhuri and Ghose (1978), Ghose and Chaudhuri (1979), Ghose *et al.* (1987) and Chakrabarti (1987, 1992) is partly pseudovitrinite/semivitrinite and partly transitory semifusinite. This transitory semifusinite + certain fraction of semifusinite are the fluorescing inertinite and these semifusinites probably are variably reactive.

CONCLUSIONS

Recognition of fluorescing structured inertinite macerals- semifusinite and fusinite (rank fusinite) adds to the overall content of reactive constituents in the inertinite-rich Indian Lower Gondwana (Permian) coal seams. Though, the coals studied are only of high volatile bituminous rank, the increase in their proportions of reactive macerals may prove useful in considering them for blending purposes provided carbonization tests give satisfactory results.

The fluorescence exhibited by a fraction of inertinite appears to be related with its genesis from partial oxidation of resin/bitumen impregnated cell walls of gymnospermous plants which served as source for the formation of Indian Lower Gondwana coals.

As described the maceral 'semivitrinite' (of Bureau of Indian Standards, 1992) or 'semifusinite A' is pseudovitrinite (Stach *et al.*, 1982) or vice-versa. However, this maceral as recognised by some Indian workers appears to be encompassing partly semi-

vitrinite/semifusinite A and partly fluorescing semifusinite as recognised presently.

ACKNOWLEDGEMENTS

The authors thank Drs Hari K. Maheshwari (Head) and Ashwini K. Srivastava of the Department of Palaeophytic Evolutionary Botany of this Institute for fruitful discussions on Permian plant megafossils. We are grateful to Dr G.H. Taylor, Emeritus Professor, Research School of Earth Sciences, The Australian National University, Canberra for reviewing the manuscript and giving constructive suggestions.

REFERENCES

- Ammosov II, Eremin IV, Sukhenko SF & Oshurkova LS 1957. Calculation of coking charges on the basis of petrographic characteristics of coals. *Koks i Khim* **12** : 9-12 (in Russian).
- Ammosov II, Babaschkin BG, Gretschnichnikow NP, Eremin IV, Kalmukow GS & Prjanischikow WK 1964. Genetic and technical coal classification in USSR. *Nauka : Moskwa* (in Russian).
- Benedict LG, Thompson RR, Shigo III JJ & Aikman RP 1968. Pseudo-vitrinite in Appalachian coking coals. *Fuel*, **47** : 125-143.
- Bharadwaj DC 1974. On the classification of gymnospermous *Sporae dispersae*. *Symp. Structure, Nomenclature and Classification of Spores and Pollen, Spl. Publ.* **4** : 7-52. Birbal Sahni Institute of Palaeobotany, Lucknow.
- BIS (Bureau of Indian Standards) 1992. *Methods of petrographic analysis of coal. Part 1 - Definition of terms relating to petrographic analysis of coal.* IS 9127 (Part 1) UDC 662.66:552.1 : 001.4, New Delhi, pp. 1-4.
- Chakrabarti NC 1987. Petrography and rank in relation to coking characters of certain coal seams in Sohagpur Coalfield, Madhya Pradesh. *Proc. natn. Sem. Coal Res. India, Varanasi* : 244-263.
- Chakrabarti NC 1992. Fluorometric study of macerals and rank characterisation of Tertiary and Permian coals of India. *Indian Minerals* **46**(1): 13-24.
- Chaudhuri SG & Ghose S 1978. A preliminary study of reactive semifusinite of Indian coking coals. *J. Mine Metals Fuels* **26**(3) : 137-141.
- Diessel CFK 1985. Fluorometric analysis of inertinite. *Fuel* **64** : 883-892.
- Diessel CFK & Wolff-Fischer E 1987. Coal and coke petrographic investigations into the fusibility of Carboniferous and Permian coking coals. *Int. J. Coal Geol.* **9** : 87-108.
- Ghose S & Chaudhuri SG 1979. Evaluation of coke strength from petrographic studies. *Int. Symp. Coal Science and Technology for the Eighties.* C.F.R.1., Jealgera.
- Ghose S, Chaudhuri SG, Chatterjee CN, Alam MM & Chaudhuri N 1987. Coal petrography as a means of predicting chemical and carbonization properties of coking coals of India. *Proc. natn. Sem. Coal Res. India, Varanasi* : 264-270.
- Lin R, Davis A, Bensley DF & Derbyshire FJ 1986. Vitrinite secondary fluorescence, its chemistry and relation to the development of a mobile phase and thermoplasticity in coal. *Int. J. Coal Geol.* **6**(3) : 215-228.
- Misra BK 1992. Resino-inertinites of Indian Permian coals- their origin, genesis and classification - Reply. *Int. J. Coal Geol.* **21**: 286-289.
- Misra BK & Singh BD 1990. The Lower Permian coal seams from Singrauli Coalfield (M.P.), India— petrochemical nature, rank, age and sedimentation. *Int. J. Coal Geol.* **14** : 309-342.
- Misra BK & Singh BD 1994. Liptinite macerals in Singrauli coals, India— their characterization and assessment. *Palaebotanist* **42**(1) : 1-13.
- Misra BK, Singh BD & Navale GKB 1990. Resino-inertinites of Indian Permian coals— their origin, genesis and classification. *Int. J. Coal Geol.* **14** : 277-293.
- Ottenjann K, Wolf M & Wolff-Fischer E 1981. Beziehungen zwischen der Fluoreszenz von Vitriniten und den technologischen Eigenschaften von Kohlen. *Int. Proc. Conf. Coal Sci., Düsseldorf, Glückauf, Essen* : 86-91.
- Ottenjann K, Wolf M & Wolff-Fischer E 1982. Das Fluoreszenzverhalten der Vitrinite zur Kennzeichnung der Kokungseigenschaften von Steinkohlen. *Glückauf* **43** : 173-179.
- Schapiro N, Gray RR & Eusner GR 1961. Recent developments in coal petrography. *Blast Furn., Coke Oven Raw Matter Proc.* **20** : 89-112.
- Stach E 1952. Die Vitrinit-Durit Mischungen in der petrographischen Kohlenanalyse. *Brennst. -Chem.* **33** : 368.
- Stach E, Mackowsky M-Th, Teichmüller M, Taylor GH, Chandra D & Teichmüller R 1982. *Stach's textbook of coal petrology.* 3rd edition, Gebrüder Borntraeger, Stuttgart.
- Taylor GH, Liu SY & Diessel CFK 1989. The cold climate origin of inertinite-rich Gondwana coals. *Int. J. Coal Geol.* **11** : 1-22.
- Teichmüller M 1982. Fluorescence microscopical changes of liptinites and vitrinites during coalification and their relationship to bitumen generation and coking behaviour. *Soc. Org. Petrol. Spec. Publ.* **1** (English translation by N Bostick, 1984).
- Teichmüller M 1986. Organic petrology of source rocks, history and state of the art. In: Leythaeuser D & Rullkötter J (Editors)—*Advances in Organic Geochemistry*, 1985 : 581-599. Pergamon Press, Oxford.
- Teichmüller M 1987. Recent advances in coalification studies and their application to geology. In: A.C. Scott (Editor) — *Coal and Coal-bearing strata - Recent Advances, Geol. Soc. Spl. Publ.* **32** : 127-169.
- Teichmüller M 1989. The genesis of coal from the view point of coal petrology. *Int. J. Coal Geol.* **12** : 1-87.
- Teichmüller M & Durand B 1983. Fluorescence microscopical rank studies on liptinites and vitrinites in peat and coals, and comparison with results of the Rock-Eval pyrolysis. *Int. J. Coal Geol.* **2** : 197-230.